VALUATION OF GEOMAGNETIC STORM FORECASTS: AN ESTIMATE OF THE NET ECONOMIC BENEFITS OF A SATELLITE WARNING SYSTEM

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Heightened solar activity, associated with increased sunspots and solar flares, sometimes produces geomagnetic storms on Earth. Such storms can affect human activity in a number of ways.

Perhaps the most important economic effect of geomagnetic storms is on electric power systems. In these systems, storms can induce unwanted currents that disrupt systems and may produce a blackout. Geomagnetic storms can also damage sensitive electronic equipment in Earth-orbiting satellites or cause satellite orbits to decay prematurely as the Earth's atmosphere heats up, expands, and exerts "drag" on the satellites. Also, geomagnetic storms can disrupt communication and navigation systems. Many of these effects are transitory, but they can be very disruptive and potentially dangerous.

A large recent solar flare occurred on May 2, 1998. It caused all high frequency radio communications on the side of the earth facing the sun to fail for several minutes. Among systems affected were the frequencies used for air traffic control around Long Island, New York. While no accidents resulted, accident risk is undoubtedly heightened by such failures.

A more powerful geomagnetic storm occurred in March 1989. This storm caused Hydro Quebec's power system to fail, cutting power to the entire province of Quebec (about 6 million customers) for nine hours. A storm of this magnitude can be expected to occur again, and it could cause greater damage if, for example, it blacked out the U.S. East Coast.

With warning of an impending geomagnetic storm, it is often possible to reduce or eliminate negative consequences of such a storm. In the case of electric power, for example, ties to vulnerable systems can be reduced, reserve capacity can be increased; and preparations can be made to handle system anomalies manually.

To provide reliable advance warning of storms, it is necessary to monitor solar activity with a satellite in orbit between the Earth and the sun. In conjunction with the Air Force and the National Aeronautics and Space Administration (NASA), the National Ocean and Atmospheric Administration (NOAA) has proposed such a satellite. With this satellite, warning of impending geomagnetic storms could be provided as much as two hours in advance. The cost of the satellite would be $75 million, plus $25 million for operational costs of the storm warning system over the three-year expected life of the satellite.

To determine whether such a system makes economic sense, the economic value of such storm forecasts must be estimated. The following estimate includes only benefits to the electric power system, and thus it is a low estimate of the true value of the system. Omitted civilian benefits include reduced risk of damage to civilian satellites and of disruption of communications and navigation systems. Omitted scientific benefits include reduced risks to astronauts in space and demonstration of solar sails as a viable technology for enabling the use of new orbits (e.g., "polar stationary") and interstellar exploration. Finally, national security benefits have also been omitted from this analysis.

ANALYTICAL APPROACH TO VALUING INFORMATION

In general, calculating a value of information requires two numbers. First is the expected benefit or cost that results if the information is absent, and second is the expected benefit or cost that results if the information is present. The difference between these two numbers represents the expected value of the information. For each case (information present or information absent), expected benefits or costs are calculated assuming that any actions taken are the optimal actions to take, given the uncertainties that exist for that particular case.

For the value of information contained in geomagnetic storm forecasts, the relevant numbers to be calculated are expected costs. To calculate the expected cost if there is no forecast, the following data are required:

1. The monetary damage that could result from a geomagnetic storm.
2. The probability of a geomagnetic storm capable of producing these damages.
3. The cost of preparations that might be undertaken in anticipation of a potentially damaging solar storm.
4. The residual monetary damage from a storm when storm preparation is undertaken.

To calculate the expected cost if there is a storm forecast, the following additional data are required:

5. The error probabilities of the storm forecast (i.e., failure to predict storms that actually occur, or predictions of storms that do not occur).

DATA ESTIMATES USED

Damages that Could Result from a Geomagnetic Storm. Barnes and Van Dyke [1990] present an analysis of the possible costs of a severe geomagnetic storm for the U.S. electric power system. Their analysis posits a scenario in which electric systems in New England and New York are operating near capacity when a major geomagnetic storm strikes. These systems fail, with effects extending to Pennsylvania, New Jersey, and Maryland. Power is lost over 95 percent of this region. After 16 hours, the power loss is still 50 percent, and after 24 hours, it is 25 percent; power is not fully restored until 48 hours after the initial event. The vast majority of the costs of such an event are the costs of unserved load. Overall, the cost for this blackout is estimated to be $3.0 billion to 6.1 billion. As a point estimate of the cost of such a blackout, the following study uses $4.5 billion.

Prior Probability of Damages. The United States has not experienced a blackout of the severity described earlier, although a blackout of Hydro-Quebec in 1989 cut power to more than 6 million customers. It is believed, however, that severe blackouts have become much more likely than they were in past years, due to the increasingly interconnected nature of our electric systems, and relatively low levels of excess capacity as a result of few new power plants having been built. In addition, there seems to be a long-run secular trend toward higher peaks in solar activity with each successive sunspot cycle. The assumption is that a potentially damaging storm might occur once in 10 years.

If a potentially damaging storm occurs, it presents a risk to power systems over a period of perhaps 24 hours. However, approximately half this risk is concentrated at the instant the storm starts, with the remainder of the risk spread over the rest of the period. Since actions to prevent damage can be implemented in approximately one-half hour, most of the risk extending over the 24-hour period can be nullified by taking action after a storm commences—that is, even if there is no warning of a storm. Thus the risk of concern for valuing a warning system is the risk of instantaneous damage. In view of this, the assumption here is that the hourly risk of damage preventable with a forecast is 1/(10 years × 365 days/year × 24 hours/day) times the 0.5 probability of instantaneous damage. This prior probability is 5.71 × 10–6 each hour.[1]

[1] The prior probability of a major storm varies over the 11-year cycle of sunspot activity. Thus it is more accurate to calculate time-specific forecast benefits using time-specific prior probabilities and then average these benefits over the sunspot cycle. While it is necessary to do this in some of the sensitivity cases presented later, it is not necessary in the base case. Thus, for simplicity, the discussion is limited to calculations that use the average prior probability over the entire cycle.

Cost of Storm Preparation. Data on the cost of preparation for geomagnetic storms are difficult to find. However, one large North American utility determined the cost of being prepared at $40,000 to $90,000/hour.

On the one hand, this cost is for only one utility representing a fraction of the electric load potentially at risk from geomagnetic storms. On the other hand, the preparation costs for this particular utility may be higher than the average cost across all potentially affected utilities. Balancing these considerations, the national cost for potentially affected utilities might be three to four times the stated costs. Thus the cost range could be from $120,000/hour to $360,000/hour, with a midpoint of $240,000/hour. This study uses the midpoint value.

Residual Monetary Damages. The monetary damage from a geomagnetic storm is primarily the cost of failing to serve customers during a blackout. Assume that a blackout would be avoided if storm preparations were undertaken. Thus, as a first approximation, assume residual monetary damages are zero when preparations are undertaken.

Storm Forecast Error Probabilities. A satellite monitoring system should allow for reliable forecasts of geomagnetic storms. Experience 20 years ago with the International Sun–Earth Explorer and more recently with the Advanced Composition Explorer indicates that storm forecasts can be accurate when satellite data are available. Data from these earlier satellites suggest that it is reasonable to assume that only 5 percent of the time will there be a failure to forecast an actual storm, while only 3 percent of the time will a storm be forecast when there is no actual storm.

VALUE OF GEOMAGNETIC STORM FORECASTS

In the absence of a good forecasting system for geomagnetic storms, the optimal policy is not to prepare for storms before the advent of a storm. Although the cost of a severe storm is very high, the prior probability of such a storm is low and the cost of preparation is significant. When the optimal no-preparation policy is followed, the expected hourly cost from storms is simply the hourly prior probability ($5.71 \times 10{-}6$) times the potential storm cost ($4.5 billion), or $25,700.

When there is a forecasting system with the error probabilities assumed earlier, the optimal policy is to prepare for a storm if and only if a storm is forecast. The expected cost calculations in this case involve the probabilities that a storm will or will not be forecast, the probabilities that a storm will or will not occur given that it is forecast, and the probabilities that a storm will or will not occur given that it is not forecast. These probabilities may be calculated from the assumed prior probability of storms and forecast error probabilities using Bayes Theorem.[2] Using these probabilities, the expected hourly cost when there is a forecasting system is $8,500.

The value of a forecasting system may now be calculated as the difference between the expected cost without and with the system. This difference is $17,200/hour, or about $450 million over three years. Obviously, this is well above the $100 million cost of the system.[3]

[2] Details of these calculations are available from the authors on request.

[3] This is the $75 million hardware cost of the satellite including launch, plus an estimated $25 million for operating the forecast system over three years.

VALUE OF FORECAST SENSITIVITIES

The key parameters that drive this estimate of forecast value are the damage cost of the storm* and the prior probability of a damaging storm. To explore the sensitivity of the results to these two parameters, both parameters are reduced from their base levels in steps to produce a 7 × 7 grid of parameter values for which the annual benefits of a storm forecast are calculated. These annual benefits are then summed over three years and reduced by the $100 million cost of the satellite warning system to obtain three-year net benefits.

The prior probability of a damaging storm is the expected storm frequency times the 0.5 probability of instantaneous damage. For ease of interpretation, the 0.5 probability of instantaneous damage is fixed and the storm frequency expressed in terms of expected years between storms is varied.

The sensitivity results in Figure 1 indicate that the three-year net benefits of the proposed satellite remain positive even if the damage cost is as low as $2 billion. Alternatively, net benefits remain positive if the storm frequency is as low as 1 in 22.5 years. Intermediate results can also be read from the chart; for example, net benefits remain positive even if damage cost is as low as $3 billion (the low end of the Barnes and Van Dyke estimate) and storm frequency is as low as 1 in 15 years.

CONCLUSION

The net benefits of a satellite warning system for geomagnetic storms are strongly positive and remain positive over a sizable range of less favorable values of the two

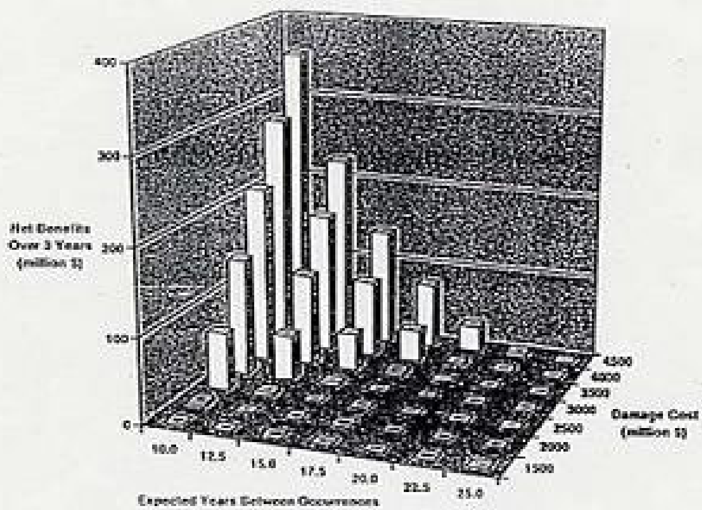

Figure 1. Sensitivity of benefits to less favorable values of key parameters

* Damage cost and residual damages after preparations are functionally similar parameters—reducing the damage cost by $1 has the same effect on forecast value as increasing the residual damage by $1.